NIF Ignition Campaign Target Performance and Requirements: Status May, 2012

Steve Haan, J. Atherton, D.S. Clark, B.A. Hammel, D.A. Callahan, C.J. Cerjan, E.L. Dewald, S. Dixit, M.J. Edwards, S. Glenzer, S.P. Hatchett, D. Hicks, O.S. Jones, O.L. Landen, J.D. Lindl, M.M. Marinak, B.J. MacGowan, A.J. MacKinnon, N.B. Meezan, J.L. Milovich, D.H. Munro, H.F. Robey, J.D. Salmonson, B.K. Spears, L.J. Suter, R.P. Town, and S.V. Weber
Lawrence Livermore National Laboratory
J.L. Kline, D.C. Wilson
Los Alamos National Laboratory

And pretty much everybody in this room…

May 21, 2012

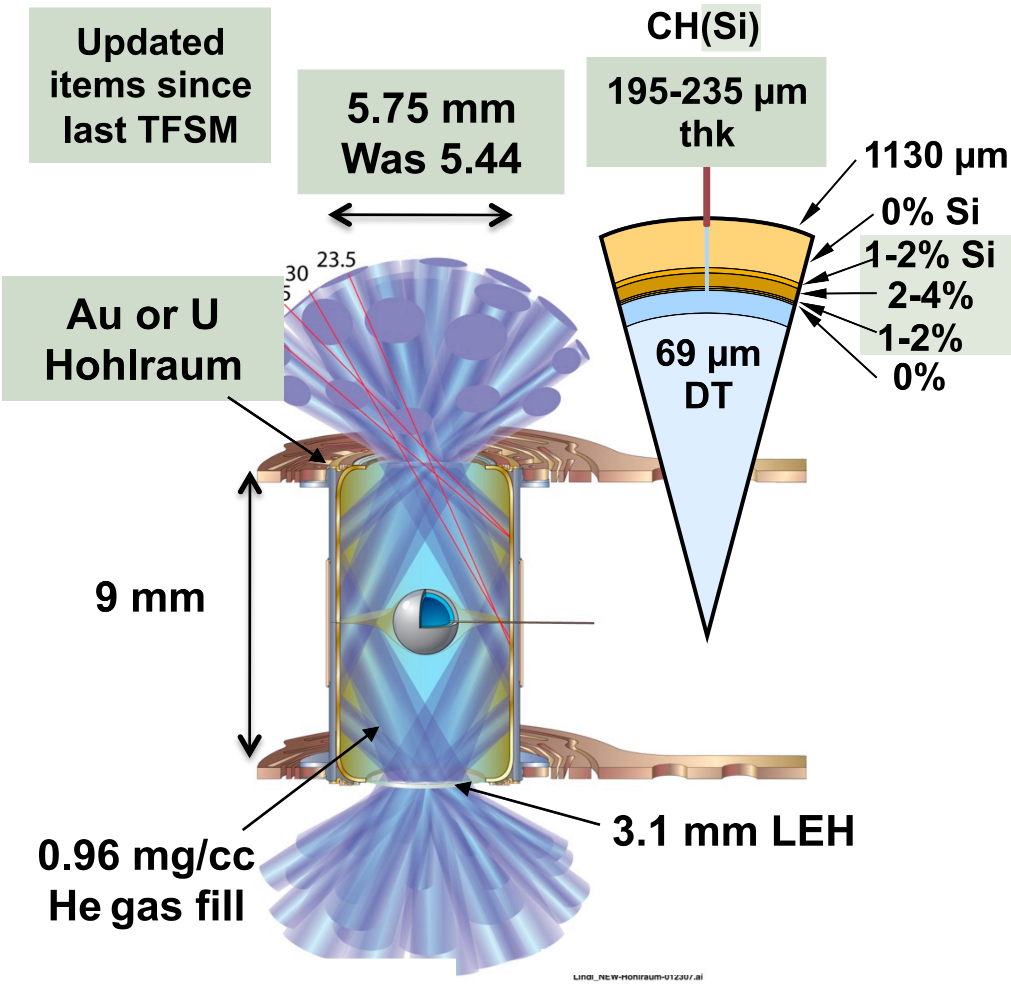
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

The National Ignition Campaign is well underway, with many successes in hand and some challenges ahead

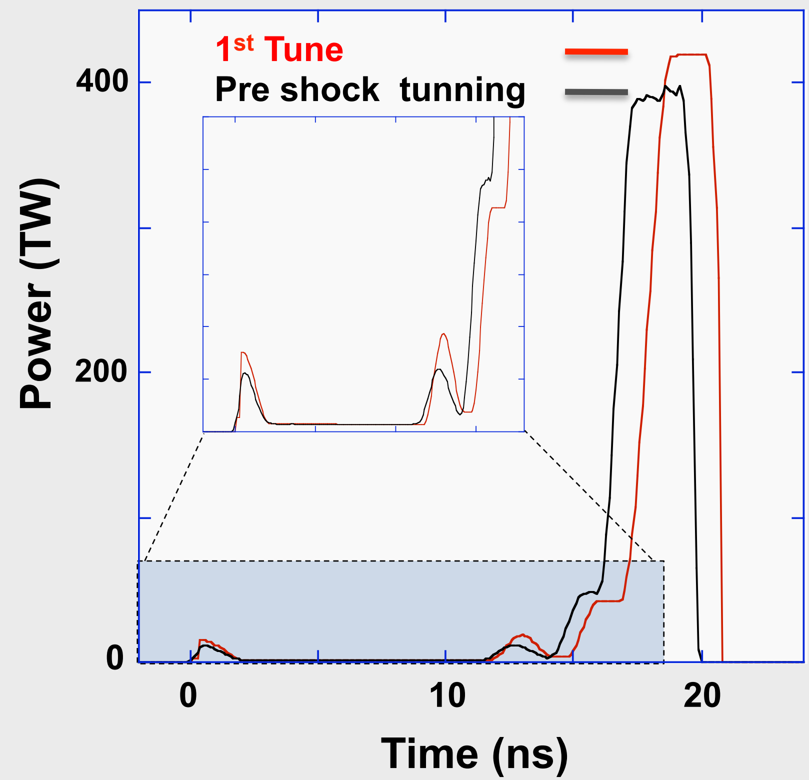
- We have successfully fielded all of the experimental platforms planned for NIC, and used the results to adjust the target design and laser pulse
- Generally, the design and requirements remain essentially the same as before the campaign began
- There have been some minor adjustments:
  - ➢Si dopant instead of Ge
  - ➢New hohlraum dimensions
  - ➢For the future, emphasis is on exploring wide range of targets including new ablators, various Si configurations, thicker shells

The target fabrication community deserves to be hugely congratulated for successfully fielding a wide variety of complex targets, meeting all requirements and a demanding schedule

Integrated implosion experiments—and soon ignition experiments—use a graded doped capsule in a Au or U hohlraum driven by up to 1.6 MJ of laser energy



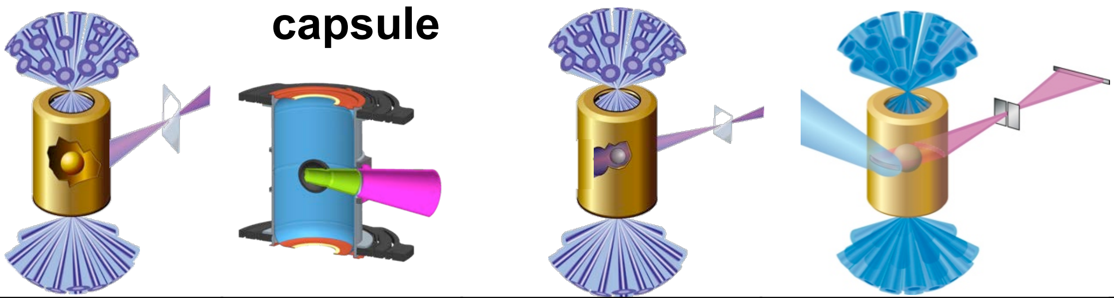
Laser pulse needs to be tuned with precision



Experiments to date have used less laser power and energy than will be needed for ignition

We use a variety of targets to tune the capsule shape, adiabat, velocity and mix

Solid high-Z sphere | **Liquid D2-filled capsule** | **Both Gas-filled and THD Cryo-layered Capsules**



Reemit	Keyhole	Symmetry Capsule	Backlit Capsule

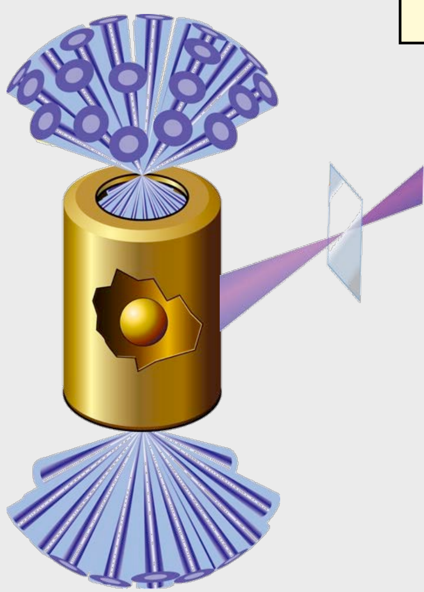
Each of these is used to optimize respective features of laser pulse or target geometry, before doing implosion with cryo layer

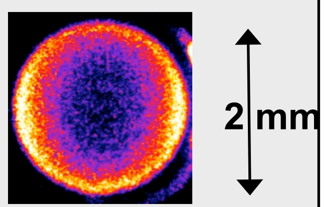
Reemission spheres were used to set cone power ratio for first 2 ns to ensure symmetric foot picket drive

Experimental Geometry

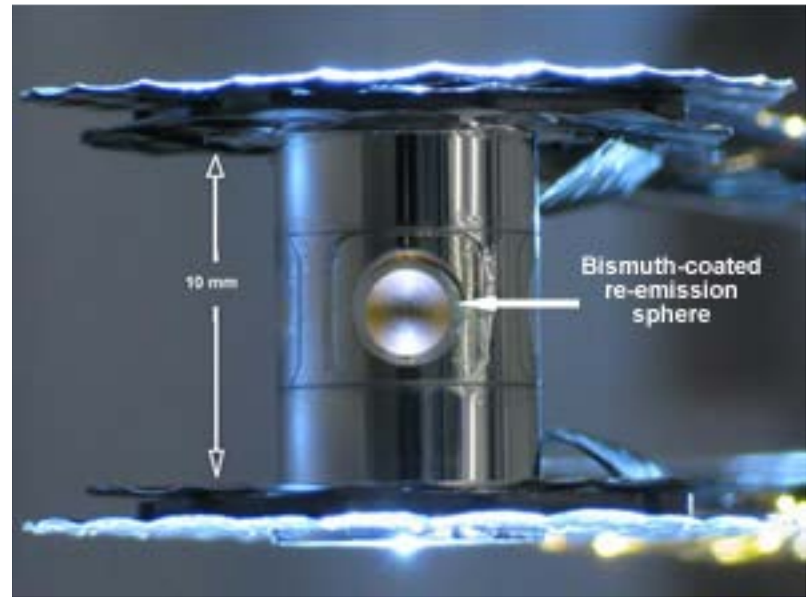
Bi sphere "Reemit" replaces layered capsule

0.7 keV Gated X-ray images





Observable:
Limb brightness vs. angle as picket cone fraction changed

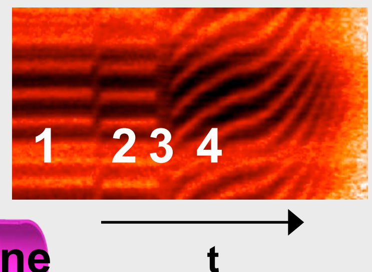


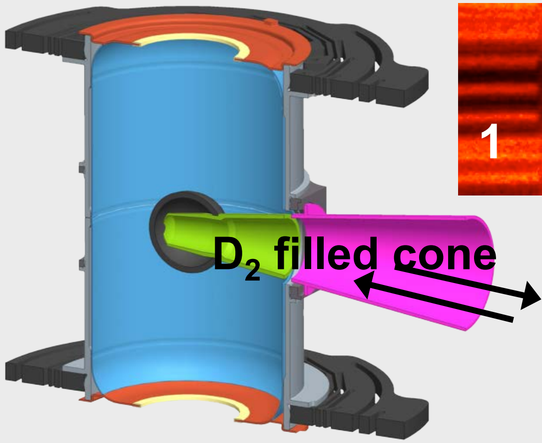
"Keyhole" targets are used to set shock strengths and timing, to minimize fuel adiabat

Experimental Geometry

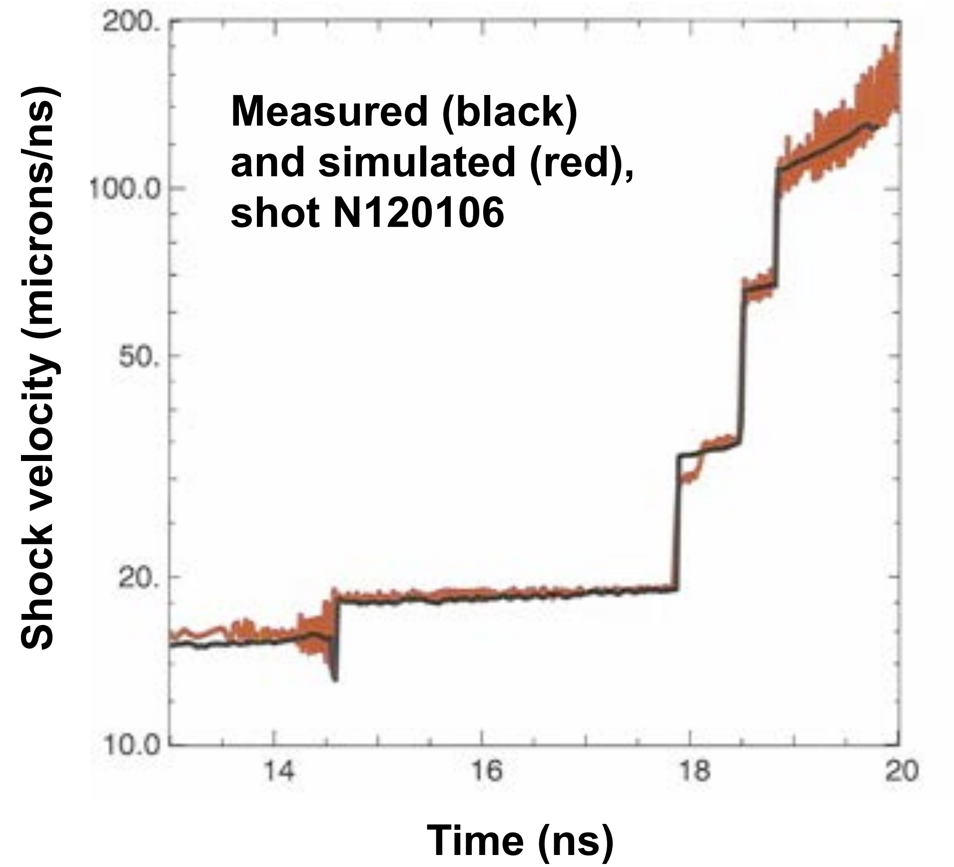
Liquid D_2-filled Cone-in-sphere
"Keyhole" replaces layered capsule

May 2011
VISAR streak



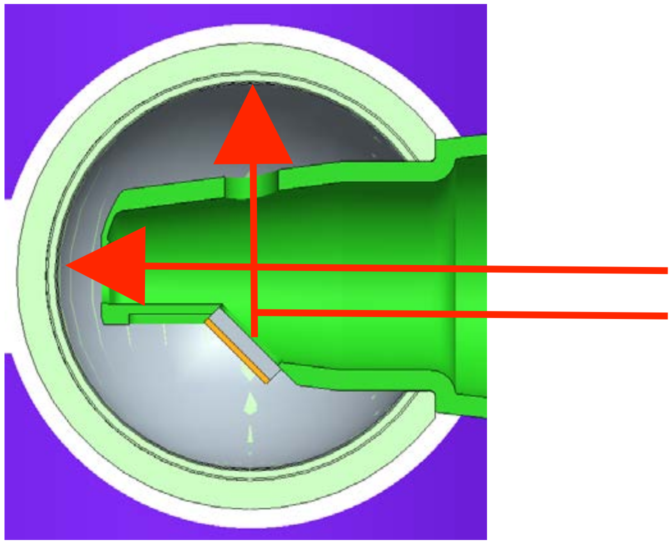


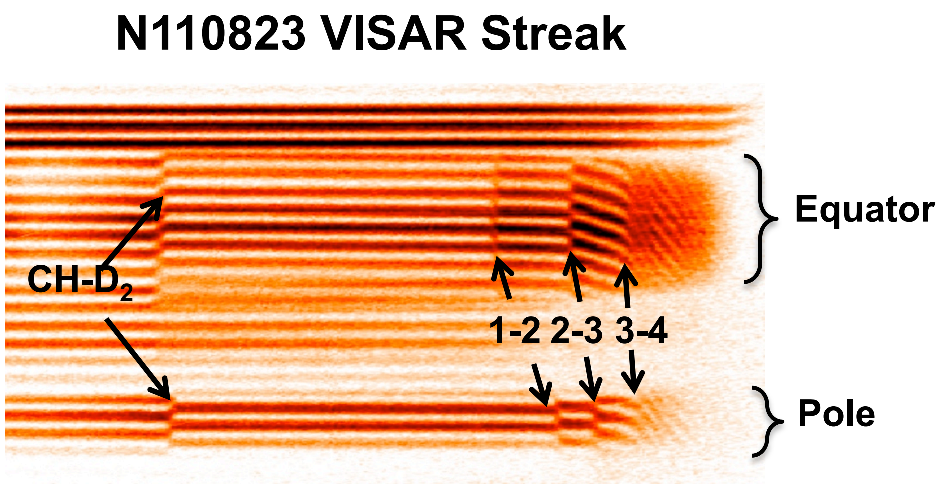
Observables:
Fringe shift(t) ~ shock speed(t)
Shock overtake distance ~ ∫vdt



Four shocks are tuned in velocity and time, to compress fuel before peak pressure for acceleration. Simulations adjusted to fit v(t).

New dual axis keyhole allows symmetrization of all shocks

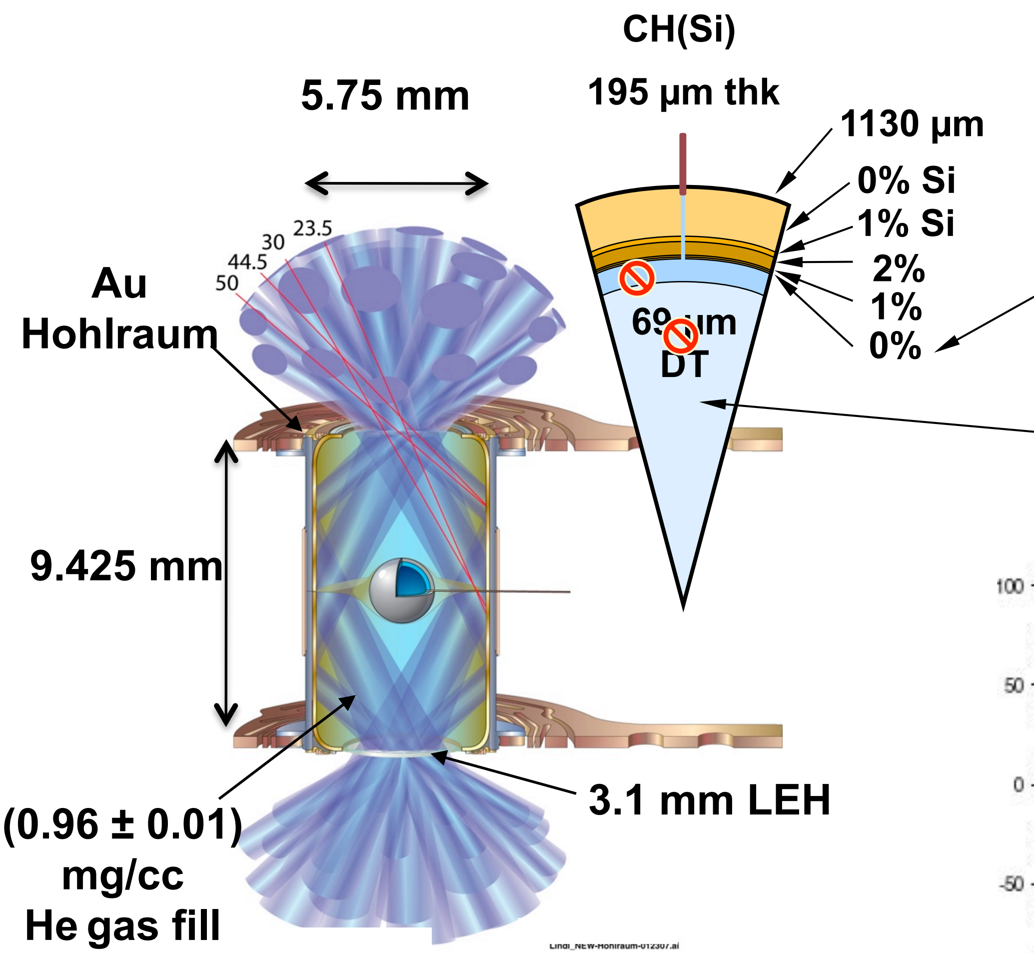


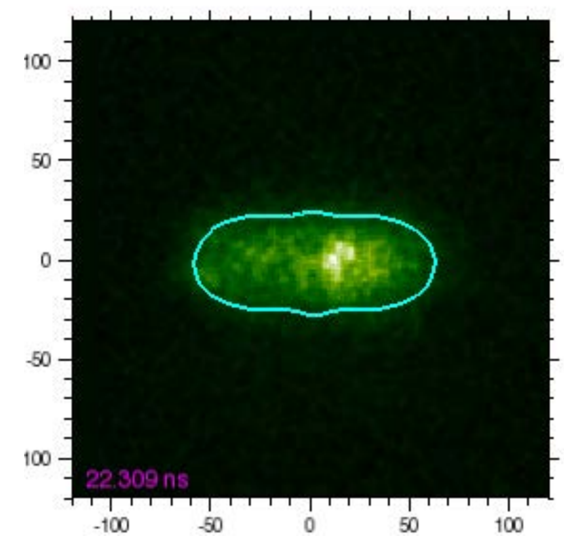


< 1% asymmetry in 1st shock velocity and breakout confirms efficacy of earlier reemit picket symmetry tuning

Set 2nd and 3rd shock symmetry (Oct 2011) to ± 3% in velocity, ± 200 ps in merge depths by varying cone fraction and power levels

Symcaps are used to tune symmetry and get first look at implosion performance





Example: X-ray emission image of Symcap N110527 was very oblate

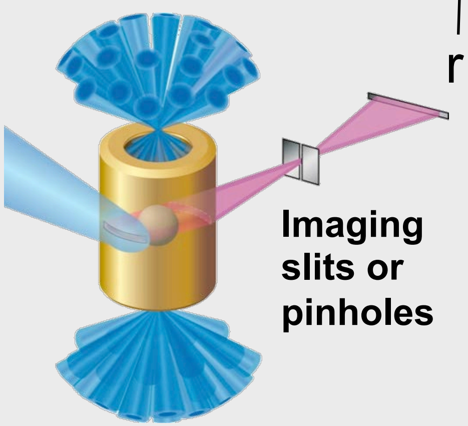
These have been completely successful and implosions are now routinely round.

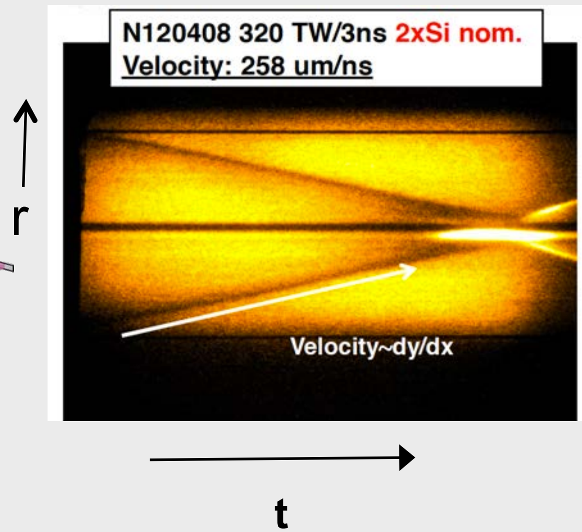
Backlit Capsule (“ConA”) measures velocity and remaining ablator mass, which sets mix susceptibility

Experimental Geometry

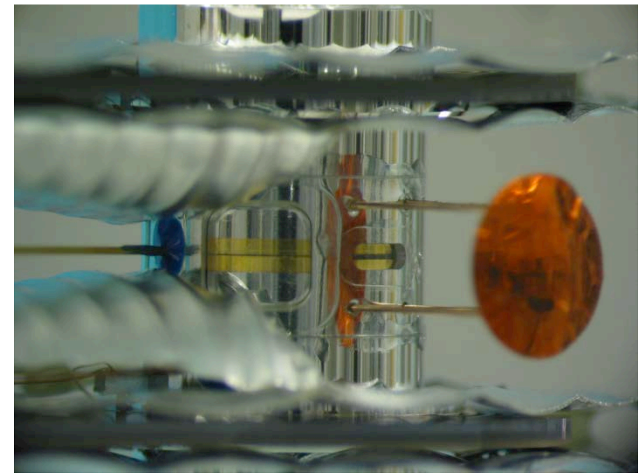
Backlit D-^{3}He-filled capsule or THD Cryo-layered capsule

Streaked or gated X-ray radiographs

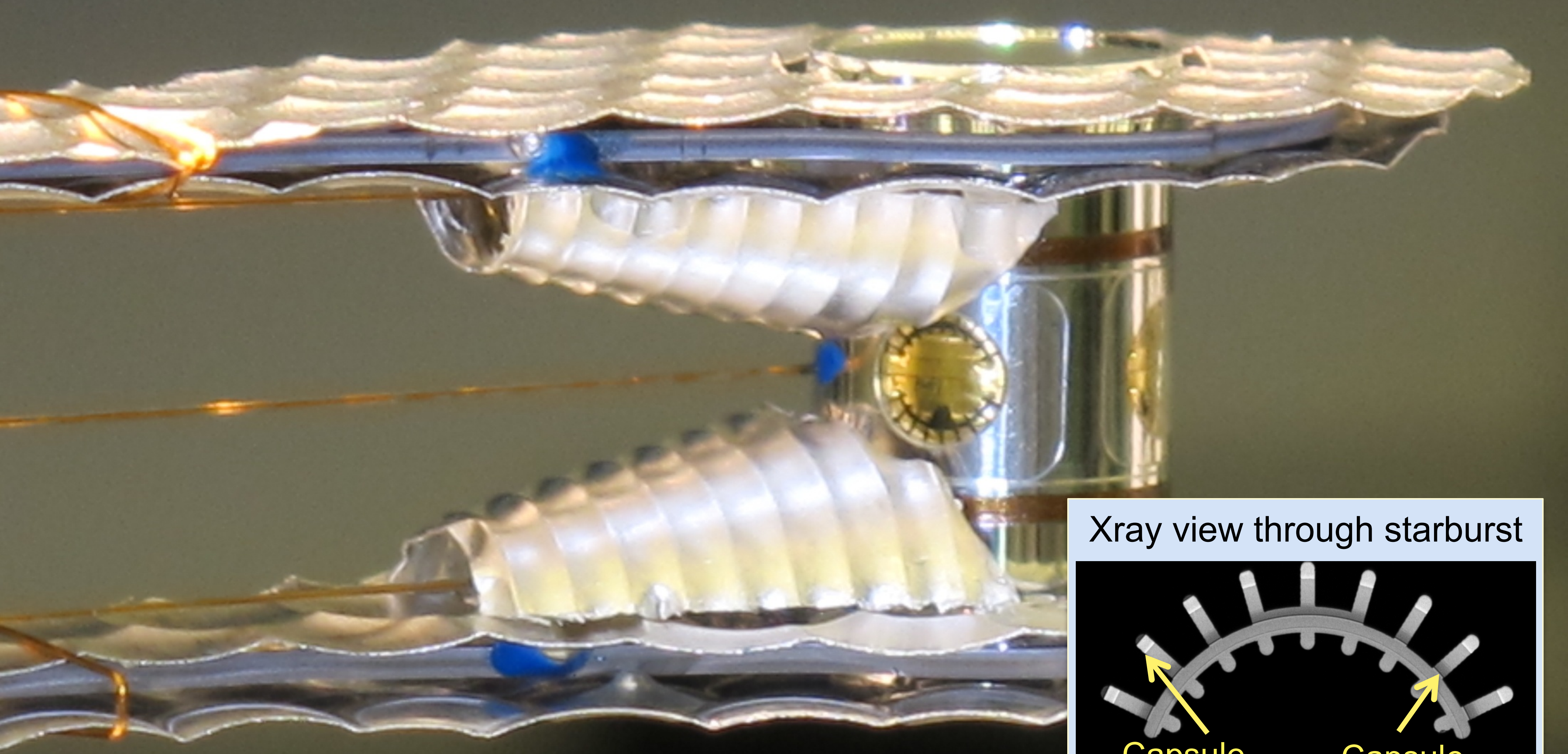




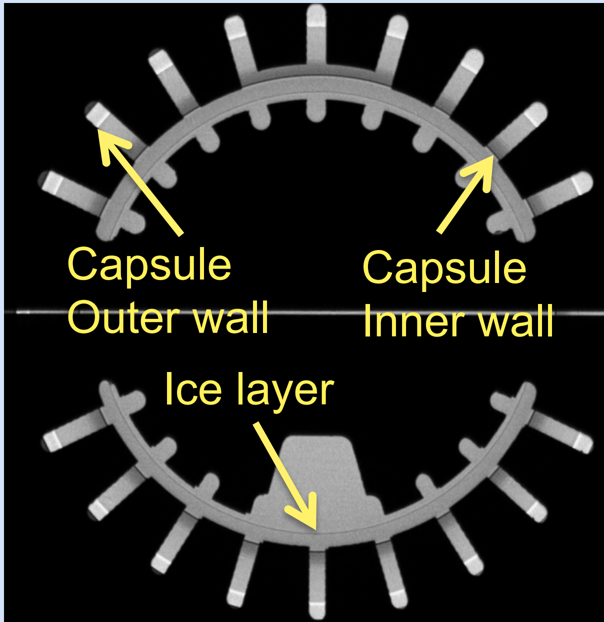
Backlighter Zn or Ge
Observables:
Radius vs time
Thickness, density, remaining mass
Limb v_{imp} at r = 300 μm



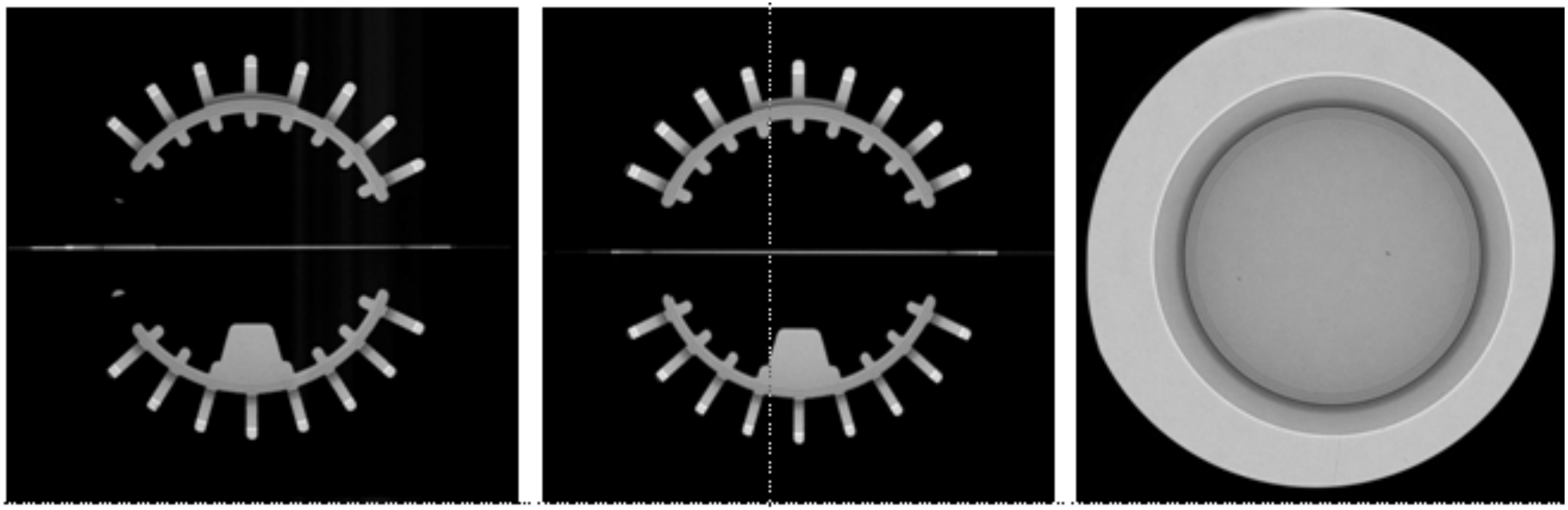
Finally, the integrated performance is measured with a layered implosion

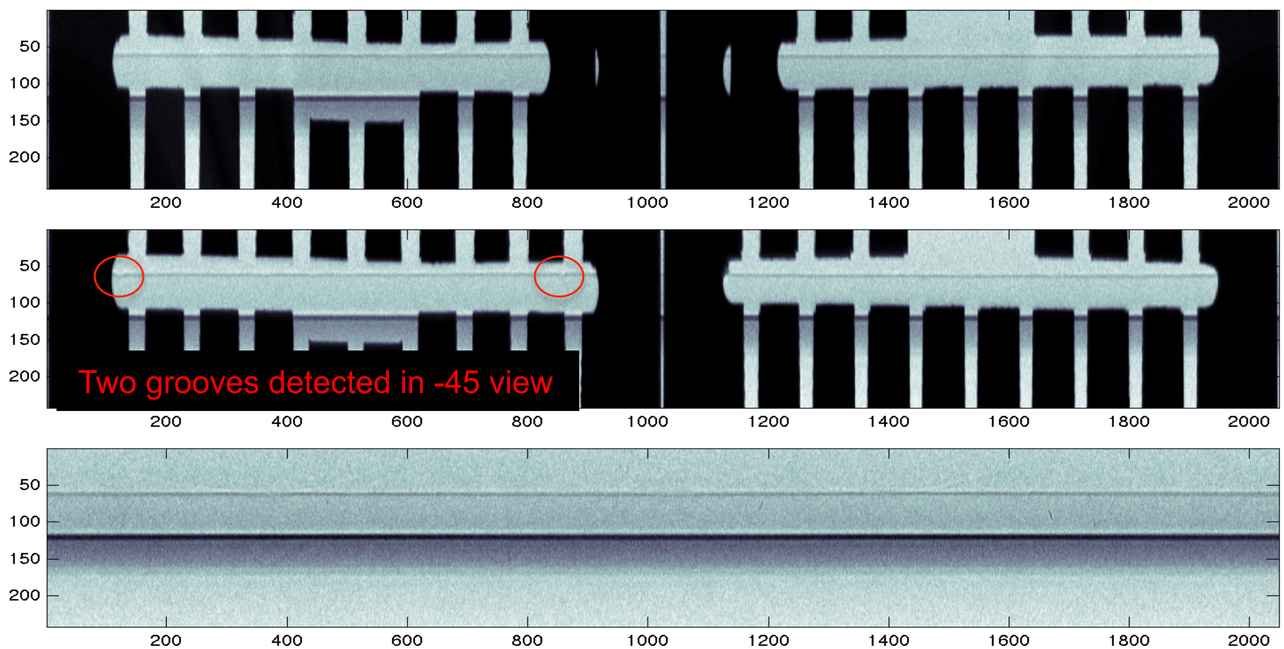


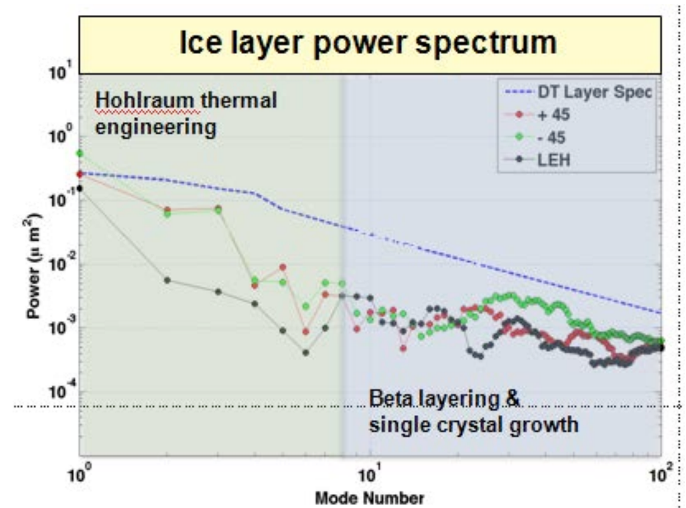
Xray view through starburst



Implosion experiments utilize THD or DT ice layers that are characterized for surface roughness and isolated defects, e.g. grooves

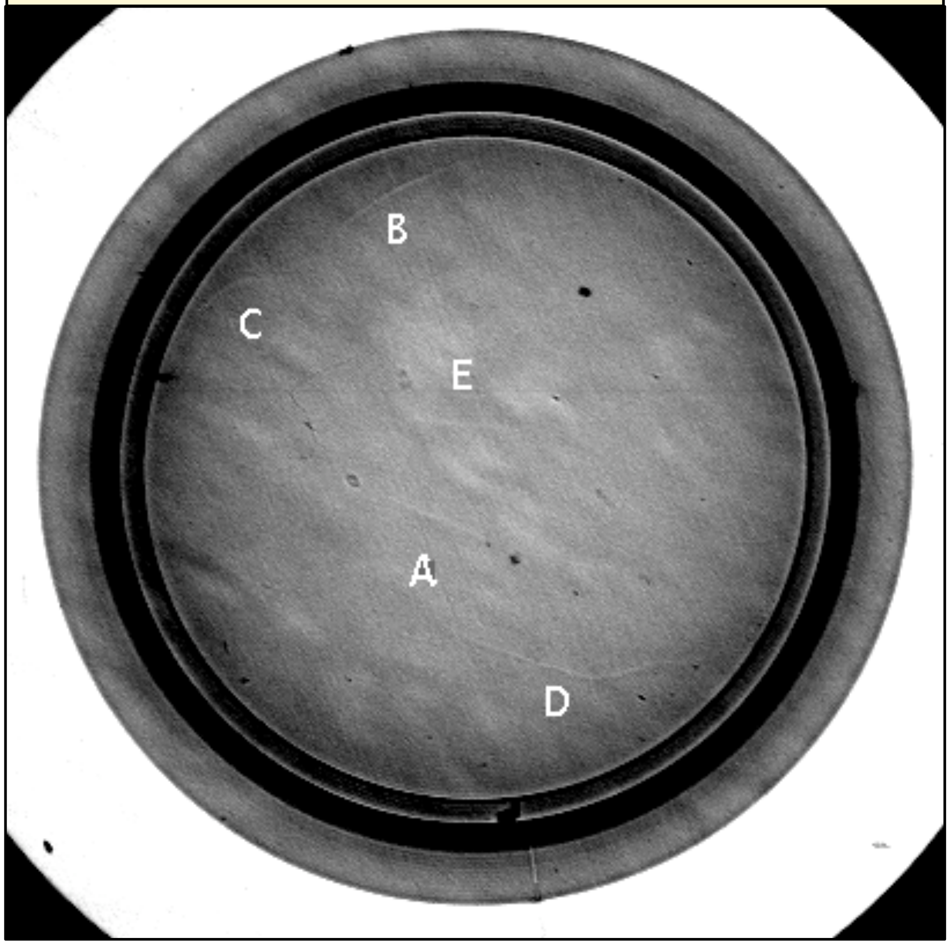






Cryo layer analysis now includes a low mag, high contrast diagnostic to observe grooves

Layer shows 5 larger grooves that result in a K value of 0.74 μm



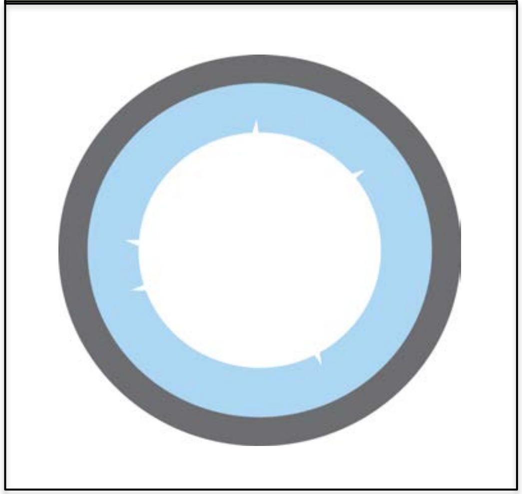
Example of groove characterization

A: 11 microns deep, Area = 518 square microns, length = 310 microns, K = 0.33 microns
B: 8 microns deep, Area = 377 square microns, length = 410 microns, K = 0.28 microns
C: 6 microns deep, Area = 283 square microns, length = 260 microns, K = 0.17 microns
D: 11 microns deep, Area = 518 square microns, length = 851 microns, K = 0.55 microns.
E: 5 microns deep, Area = 236 square microns, length = 275 microns, K = 0.14 microns.

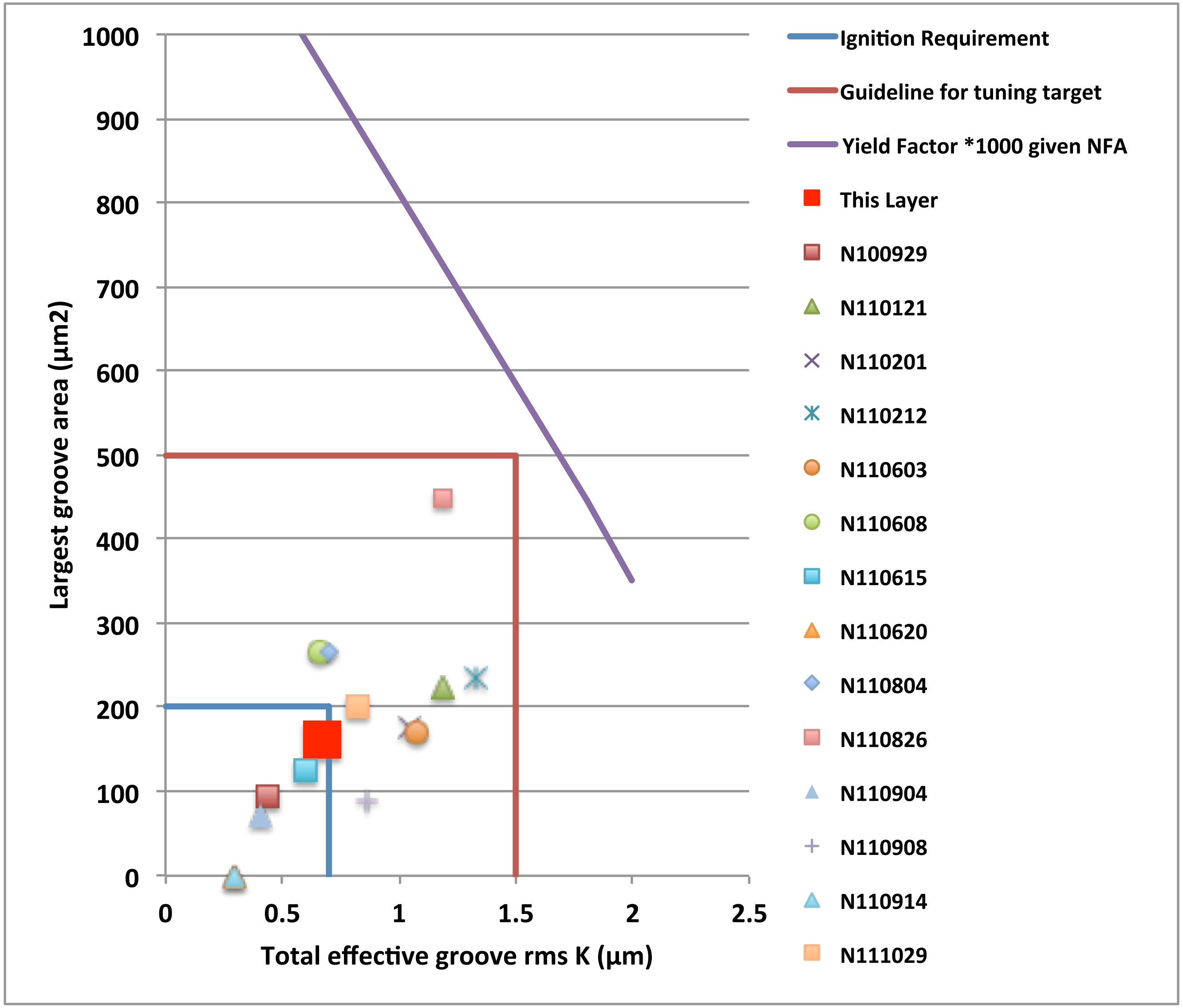
For the 5 grooves, Total K = 0.74 microns.

Integrated implosions have used THD or DT ice layers that routinely meet experiment requirements

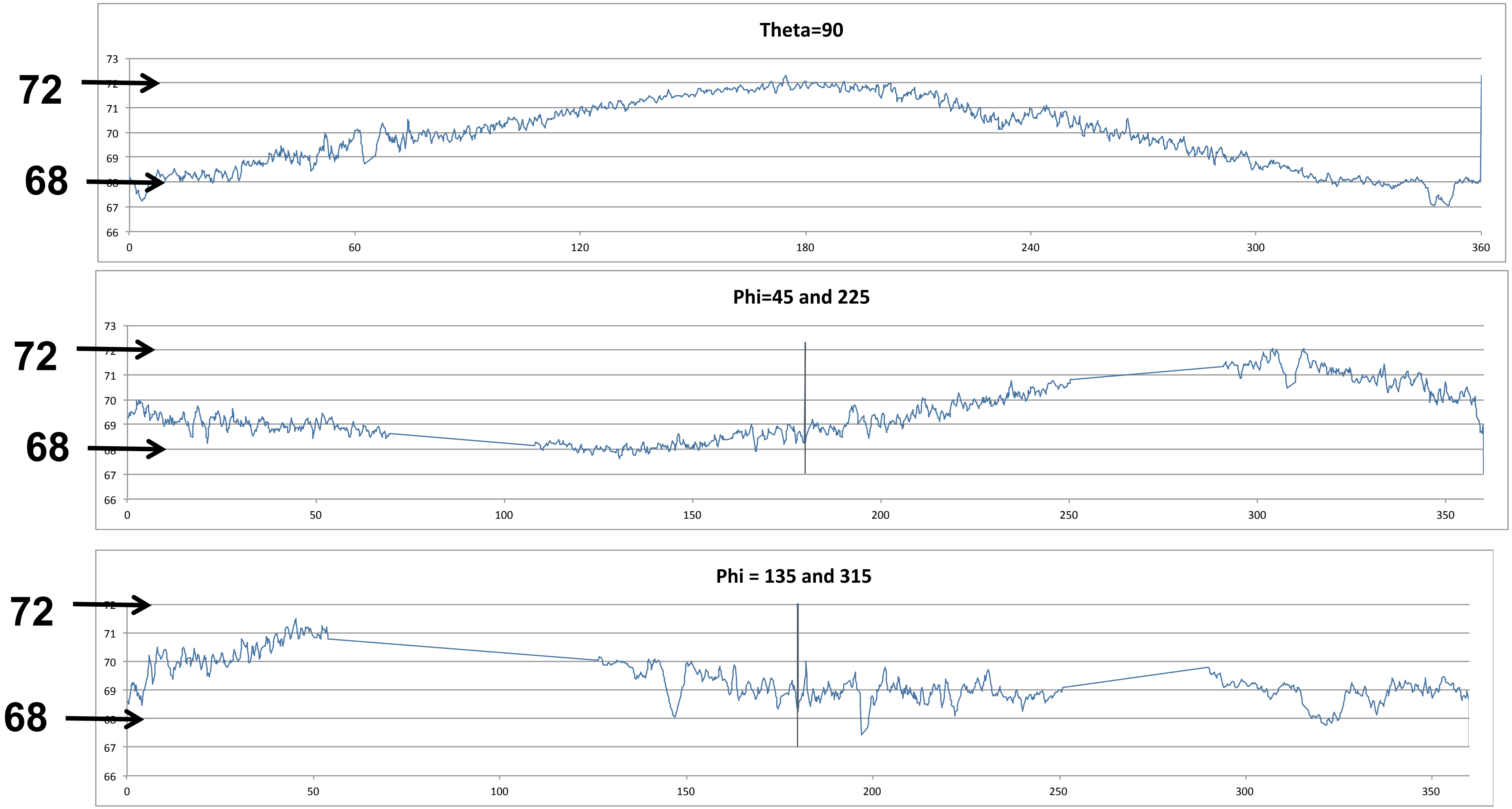
Layers have some surface grooves



$$K = \sqrt{\frac{1}{V_{fuel}} \sum_j A_j^2 L_j}$$

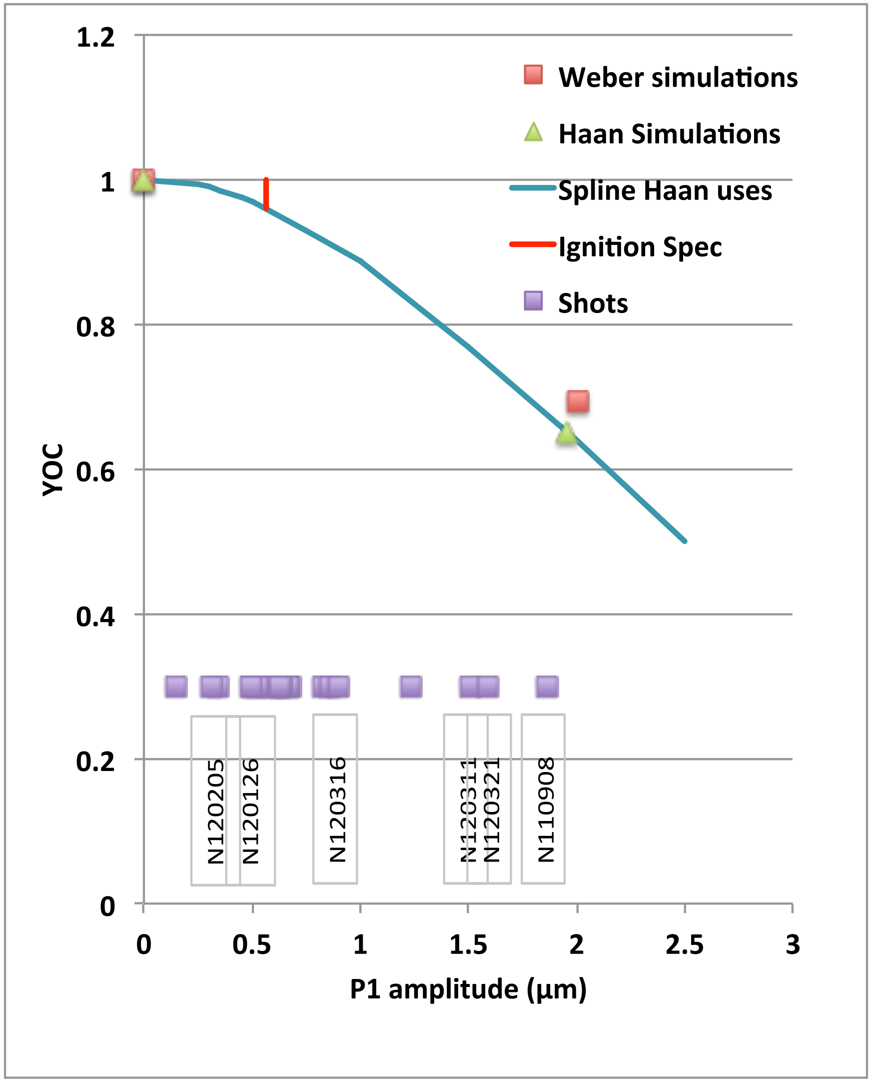


There is often a big mode 1 aligned with the fill tube



Thickness vs angle, three orthogonal views from shot N120321
Thickest at θ~90, φ~180, just opposite the fill tube
Thinnest at fill tube, θ~90, φ~0. Fill tube and support arms at φ=7 in this coordinate system

This is big enough to have a significant effect on performance



For most recent shot:

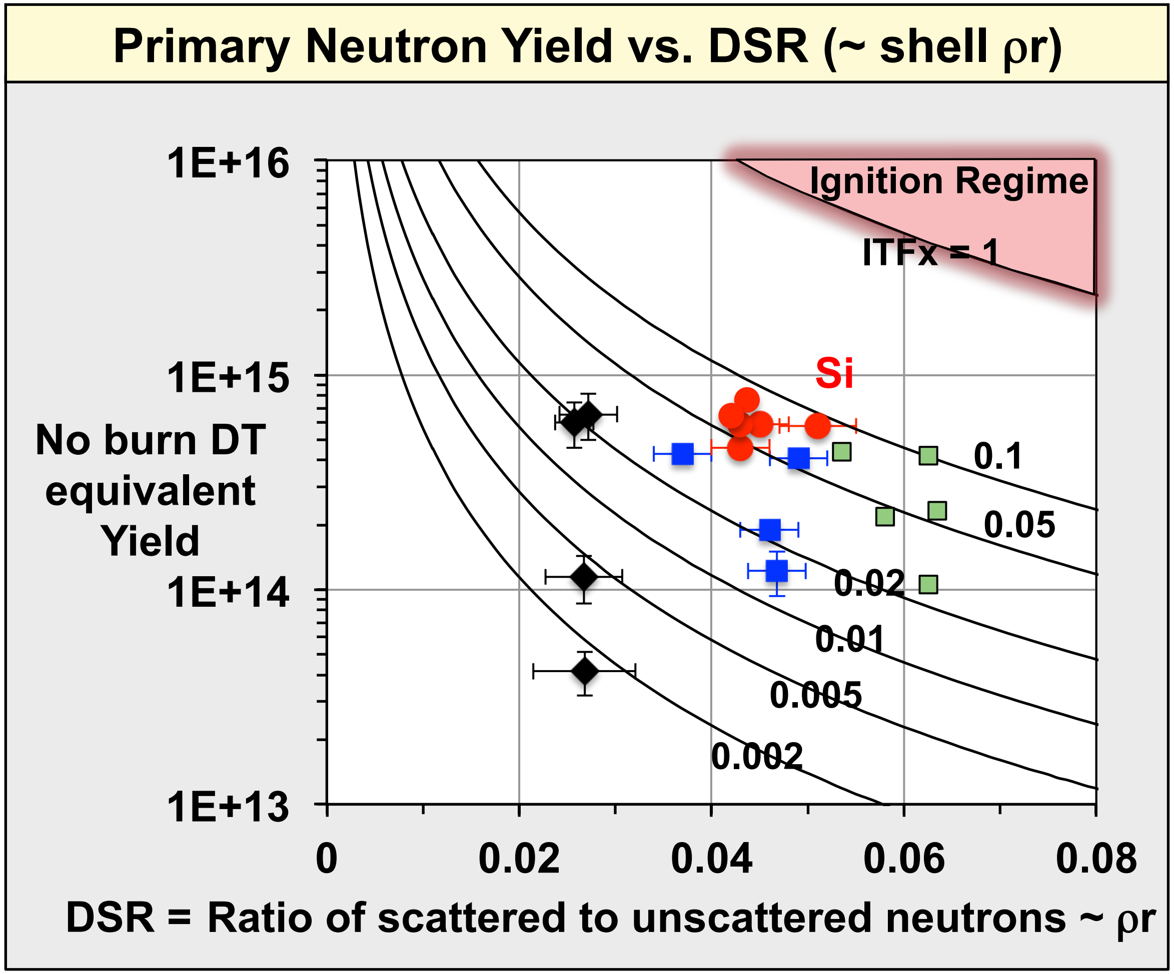
- Yield is reduced by 30%
- Tion reduced by 9%
- Average DSR is reduced by 2.8% (i.e. from 5.71% to 5.55%)
- ρR relative to original origin varies +/- 10%. ρR is high where layer is initially thin, i.e. phi~30, theta ~90
- DSR varies +/- 7%, high on side initially thin (towards 90-30)
- Primary neutron yield varies +/- 2%, is high in direction initially thick
- 17% brightness contour moved towards initially thick fuel by 5 μm
- 17% contour still within <1μm of round (very small residual m=2, 3, etc.)
- Brightest part of image is shifted toward initially thick fuel by 8 μm

Mode 1 in the ice is clearly an issue and is being addressed with another heater

For 1½ year now, THD and DT shots have been marching up in yield and compression

- ◆ Pre shock tuning early 2011
- ■ Post 1st pass shock tuning (June 2011)
- ● 5.75mm hohlraum CHSi capsule (Sept-Dec 2011)
- □ Low-power pulses, better symmetry and pulse-shaping (2012)

About half the gap between where we are and the ignition regime results from known issues that can be fixed with more laser power and energy (measured velocity). The other half represents challenges that we need to identify and solve.



More compression, higher density →

We have made a lot of progress but challenges remain

- We have successfully fielded all of the experimental platforms planned for NIC, and used the results to adjust the target design and laser pulse
- Principal challenges we are finding:
  - Velocity was 10-15% low with Ge, now ~10% low with Si dopant
  - Compression as measured by down-scattered neutrons is ~5% low
  - Yield is below simulated by 3-10x, probably because of 3D hydro
  - To get ignition at NIF scale, these 10-20% issues must be reduced to be less than about 5%, and mix made reliably lower

What are the implications for target fab of what lies ahead?

— Minimize seeds for implosion hydro instabilities

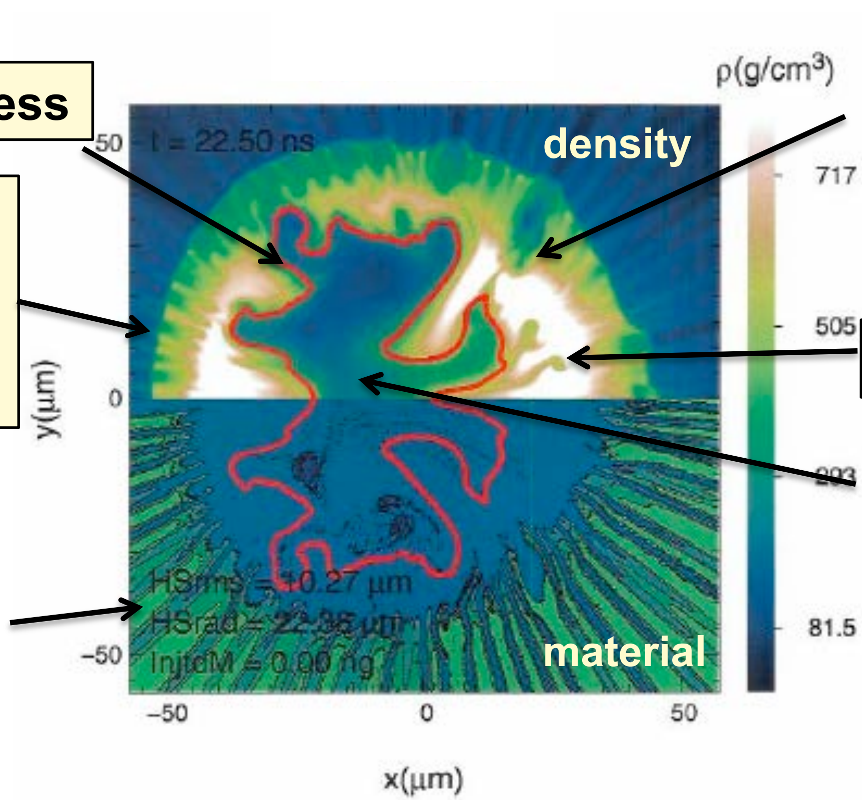
— Need operational speed and flexibility

— Wide variety of variations on the point design

— Alternate ablators

Performance is a strong function of hot spot shape and mix

2D simulation of capsule at stagnation time with roughness and ice grooves



Ice roughness

Ablator roughness (low modes <~30 feed through and grow at hot spot boundary)

Ablator

Ice grooves

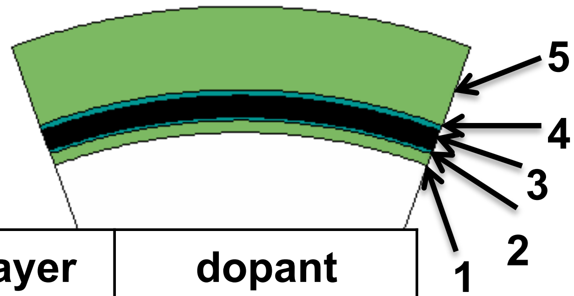
Cold shell of DT

Distorted hot spot

- Mix between cold and hot DT decreases hot spot volume, mass, and Yield
- We used simulations to set requirements on all surfaces; now moving towards experimental optimization

Special capsules and spectrometer were developed to trace origin of ablator mix in the hot spot

Cu, Ge, Si doped CH ablator



layer	dopant (atomic %)
1	Cu(0.1%)
2	Si(0.7%) Ge(0.15%)
3	Si(1.7%) Ge(0.15%)
4	Si(1%)
5	none

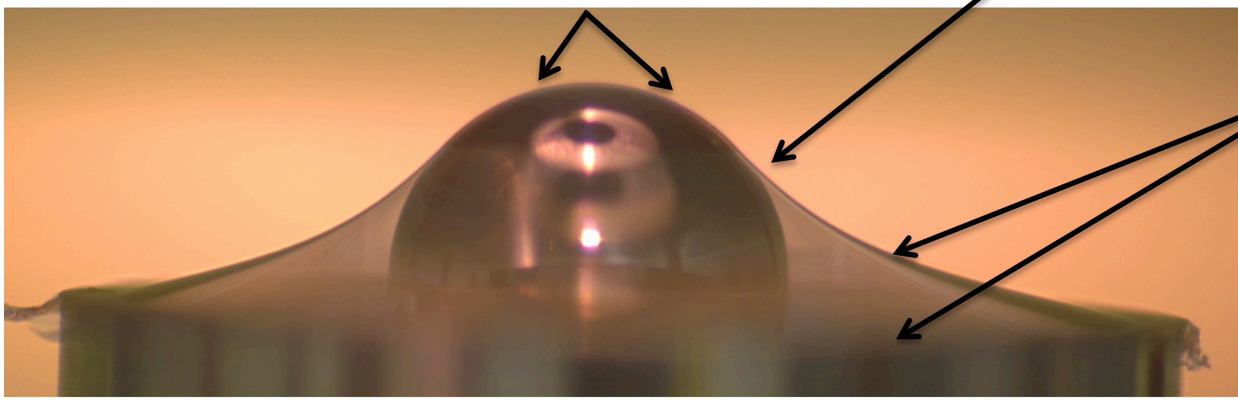
- We routinely see Ge emission lines in the core emission, measures how much Ge gets into radiating core after implosion
- Cu layer also made lines, but very faintly
- Si does not emit an x-ray line at useful energy
- This Cu/Ge/Si design told us mostly Ge layer is getting into core, as well as letting more of the high-energy x-rays out
- Imposed perturbations (laser ablated) could make the experiment controlled and quantitative
- Flexibility to design and field experiments like this will be very important in the coming years

The tent seeds a perturbation where it leaves contact with the capsule (was 300nm, now 100nm)

Here the ablator is effectively 100nm thicker

Transition of 20-300 μm lateral extent

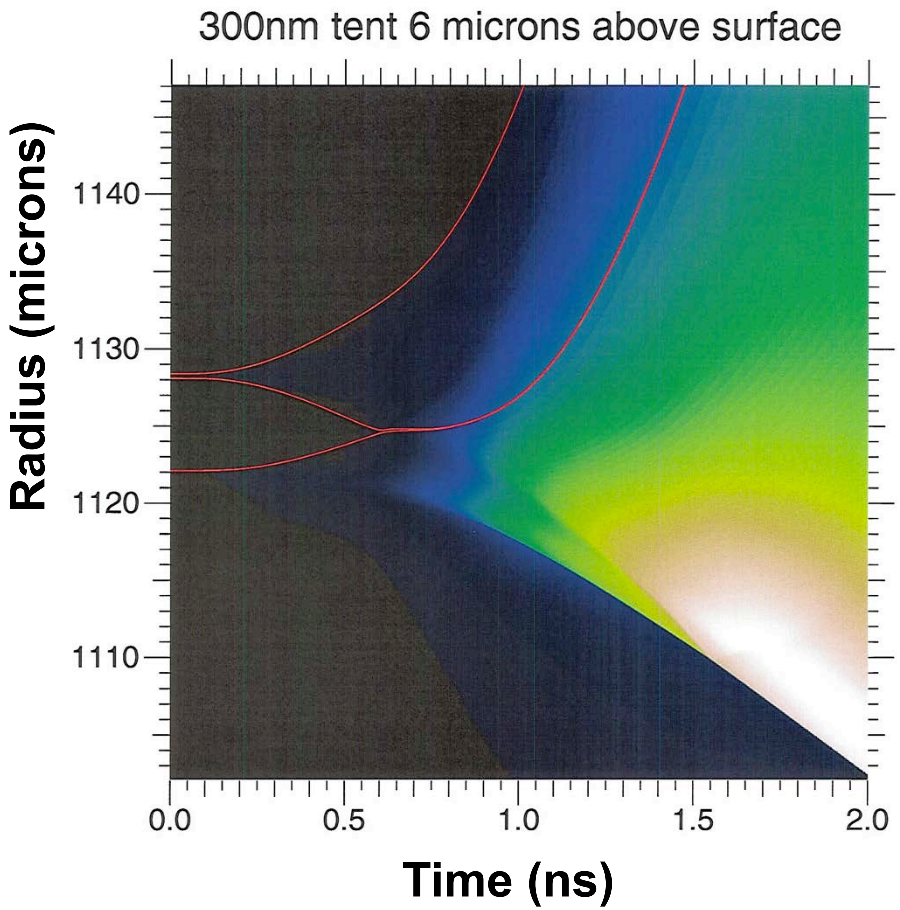
Tent has no hydro impact



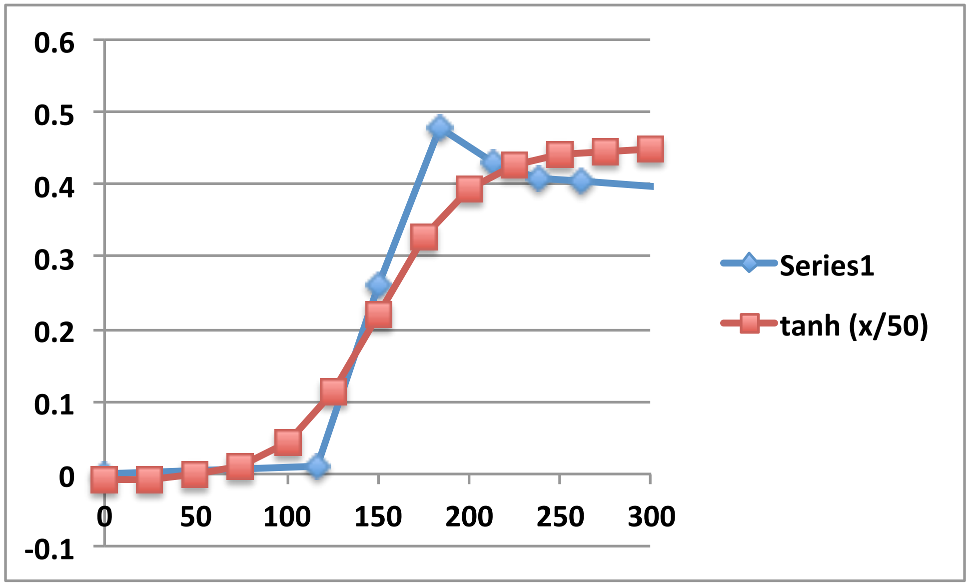
- Contact ring at ~45°. Tent safely away from surface by ~60°. Between that it is a hard-to-model perturbation shape with amplitude PTV about 100nm.
- It is very difficult to simulate this directly because the topology cannot be zoned without a significant zoning perturbation
- Our recent simulations put a tanh step at 45° with various widths

We do 1D calculations with a parallel tent at various elevations above the surface, and 2D with equivalent step on the CH surface

Color is pressure



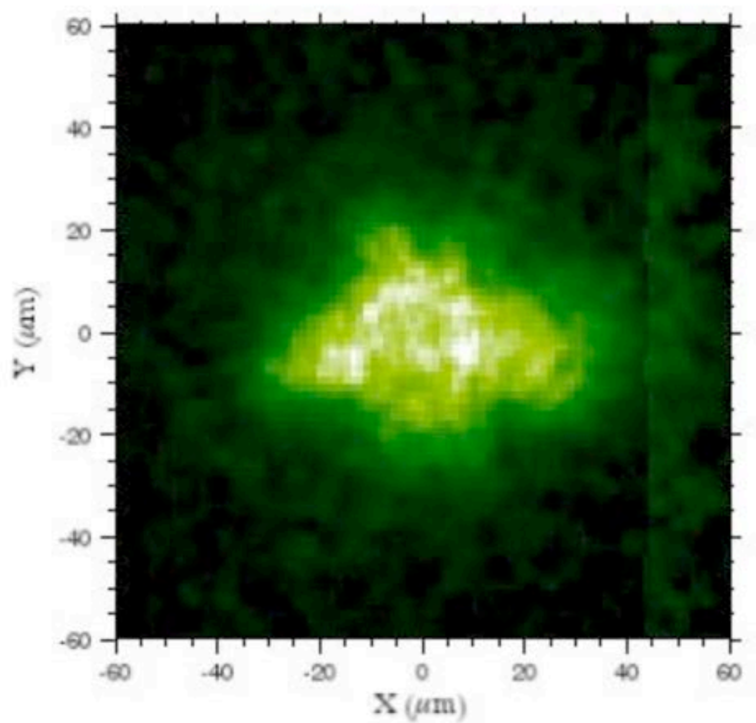
- **Displacement of shock front from 300nm tent at various elevations**

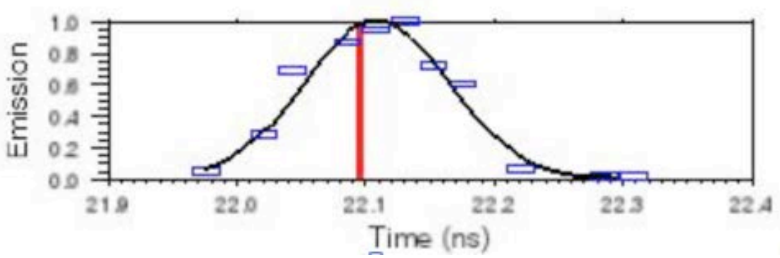


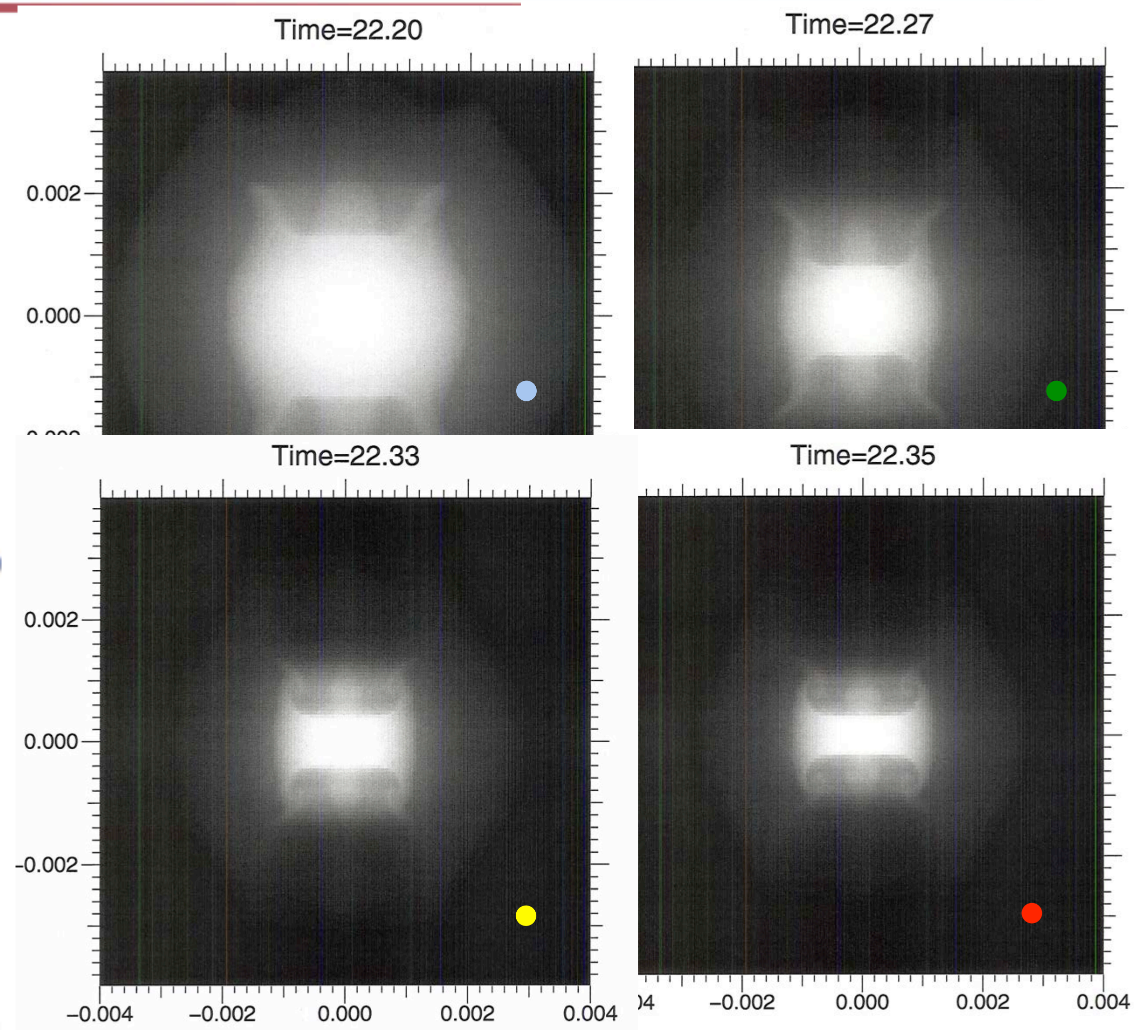
Equivalent transverse displacement from contact ring

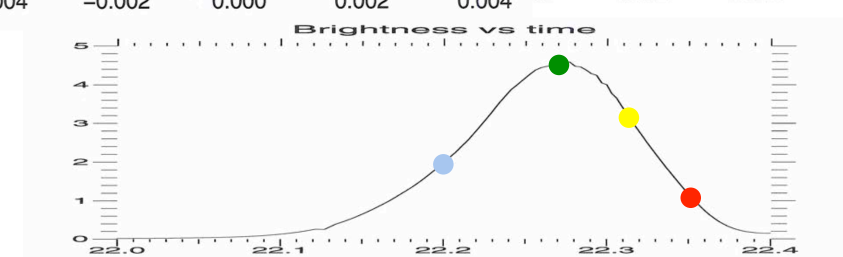
Simulations below assume 300nm step, 100 micron width. With 40 micron step the growth is ~40% more.

Simulation w/ 300nm tanh step, 100µm lateral, at 30° from pole, looks a lot like the N110904 data







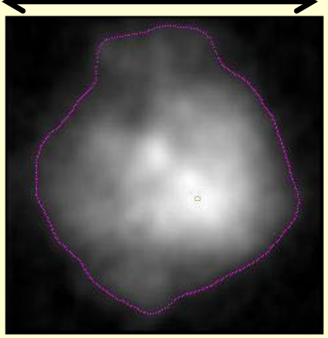


In addition to THDs, symcaps have also shown a feature that could be the tent

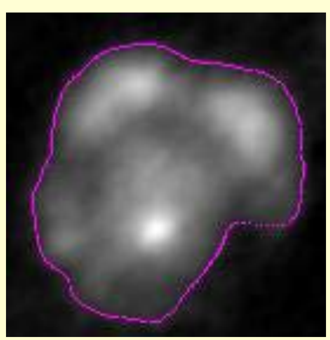
N100113

N120421 ConA (missing beams produce 3D asymmetry too)

150 μm

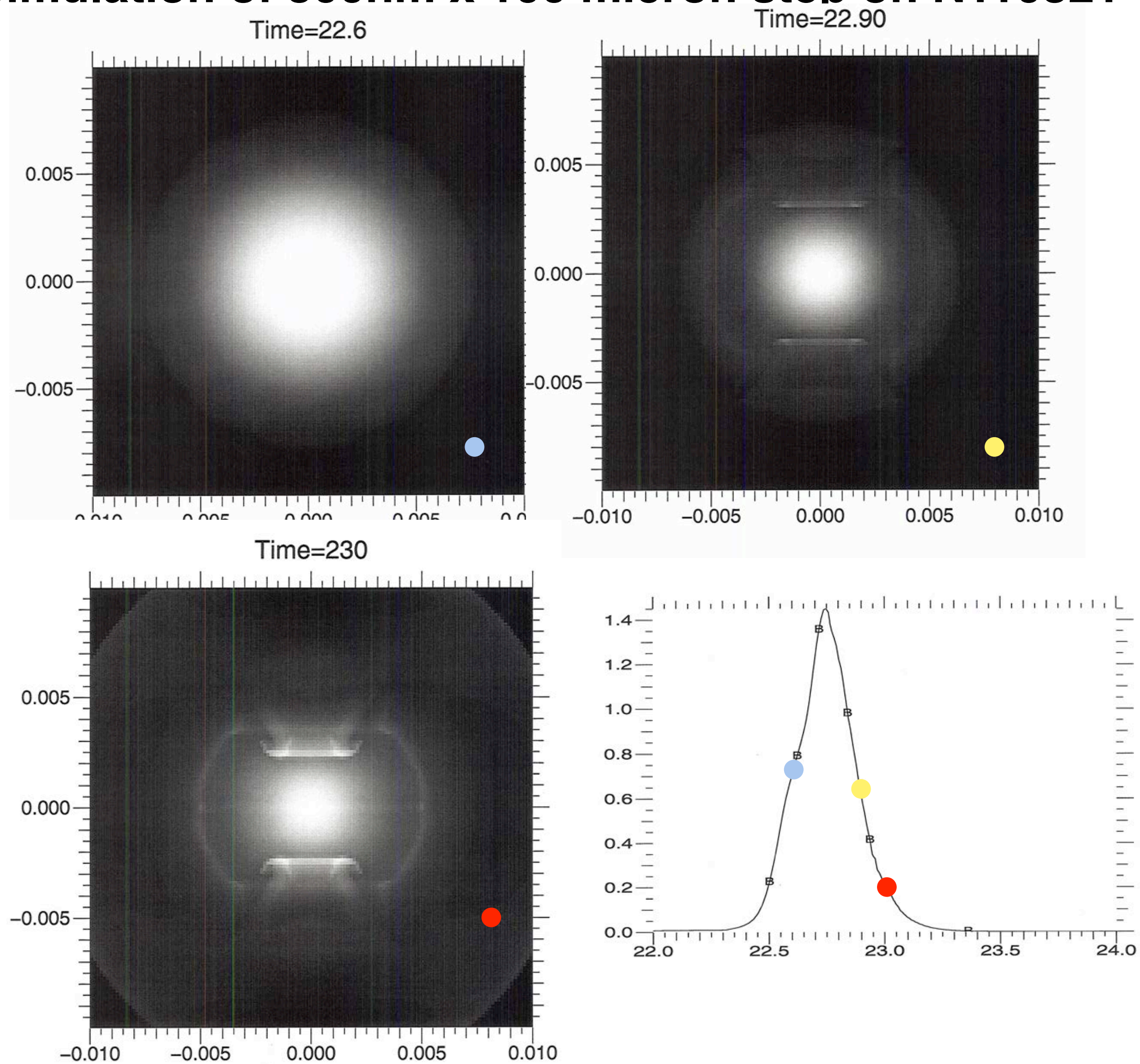


Waist view

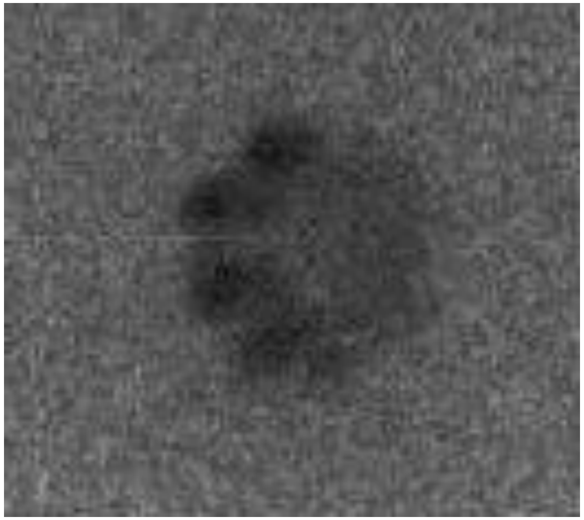


Pole view

Simulation of 300nm x 100 micron step on N110821

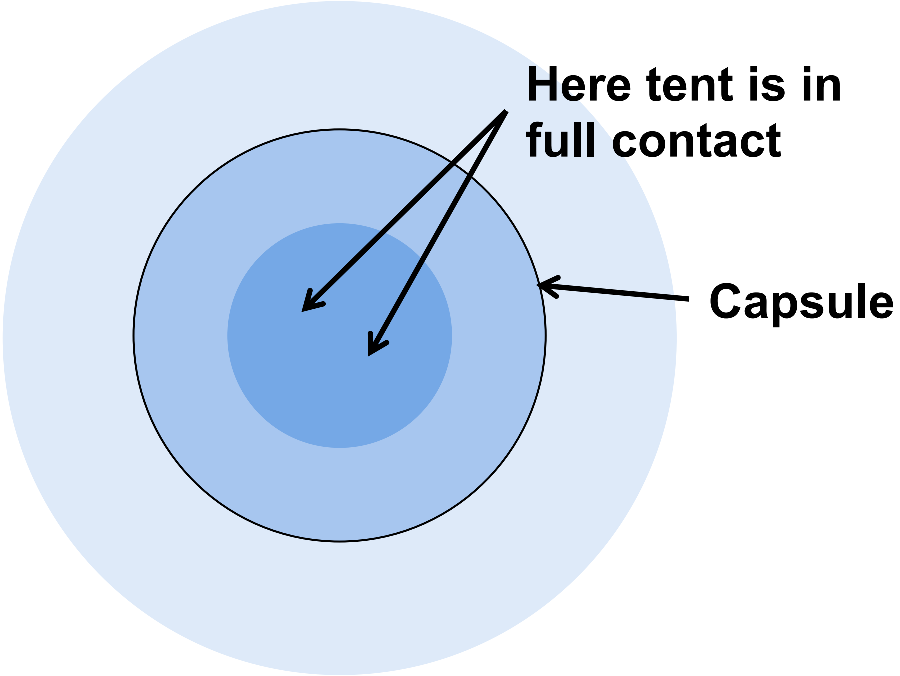


Ripples in the tent around contact ring could explain "bear-claw" image in shot N110615



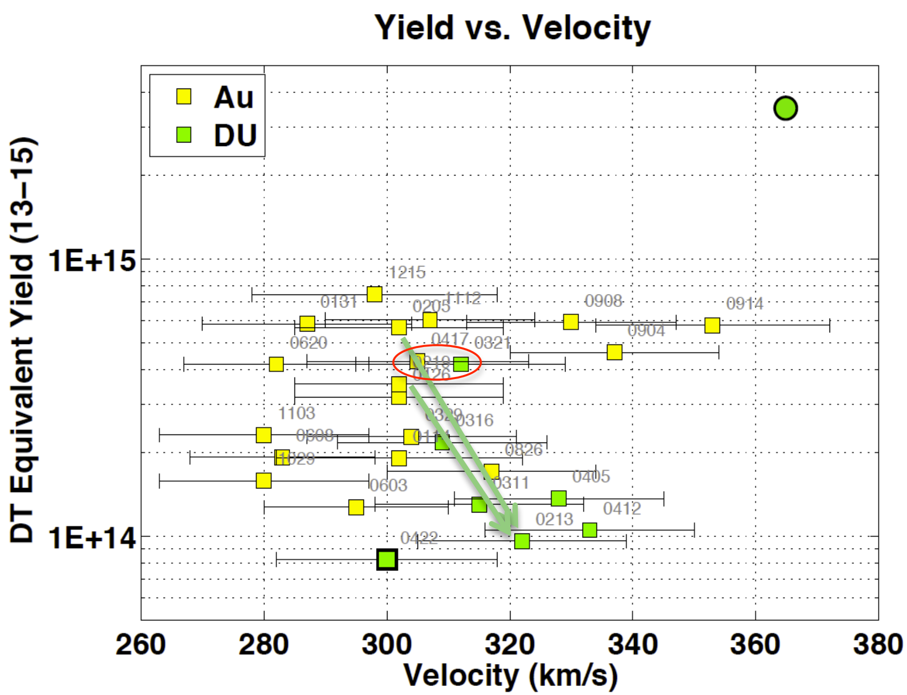
Polar x-ray emission image from DT shot N110615 (quite oblate in the other view)

The tent is important. Already reduced from 300nm to 100nm; going to 50nm is a valuable next step.



As tent lifts away from capsule surface, was it wrinkled or rippled?

Uranium hohlraums improve the drive, but may affect implosion performance



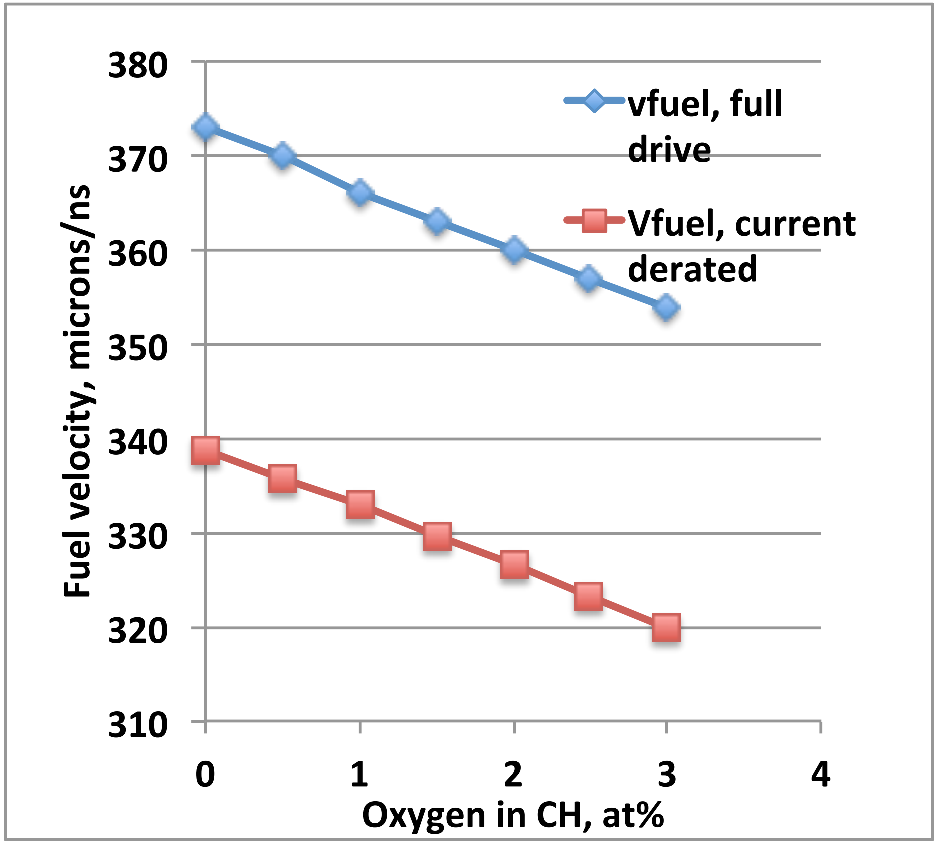
First U shot had same pulse shape, Au in N120205 and N120126, then U in N120213. Gained 15-20 km/s in implosion velocity, but yield went down.

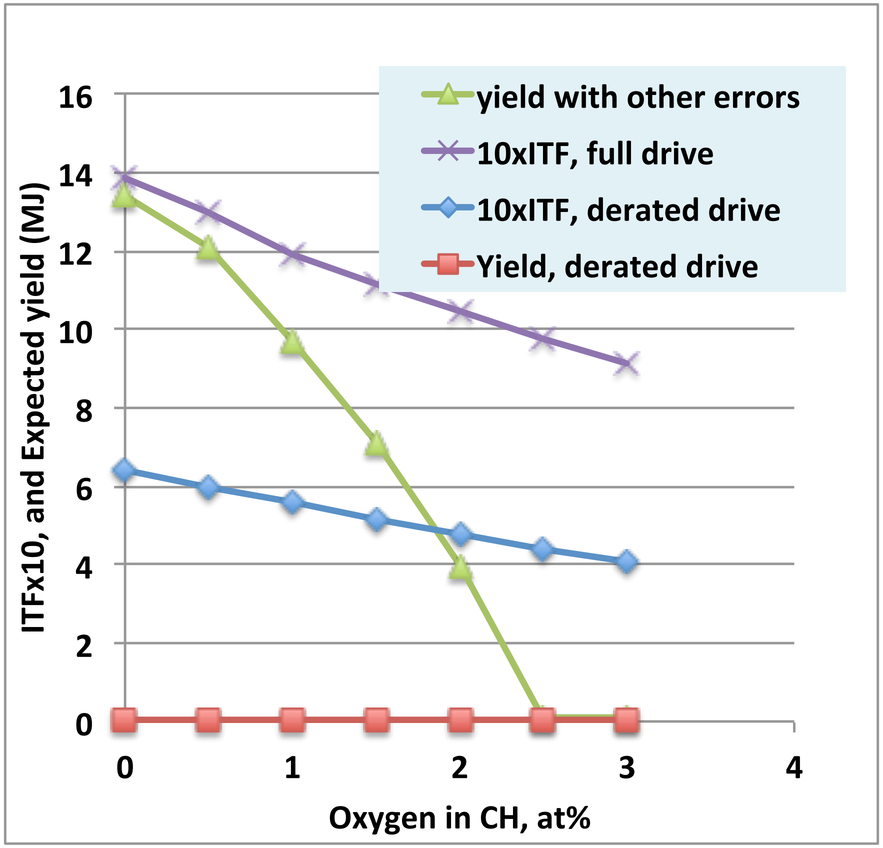
Is low yield in U shots a result of the higher drive, or something else about the U?

Tried AB comparison 120417 (Au, 345 TW) to 120321 (U, 320 TW), got same performance.

Physics community has not yet reached consensus on Au vs U issue. More tests next month (and more requests for target fab on variety of targets!)

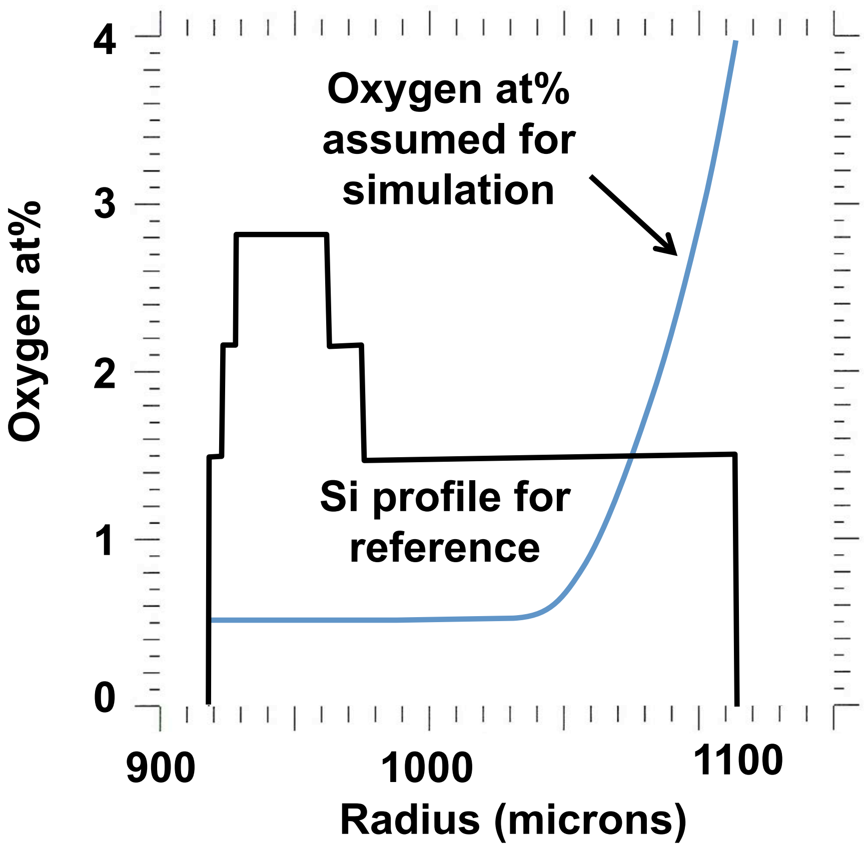
Average oxygen of 1at% or more affects implosion velocity unacceptably

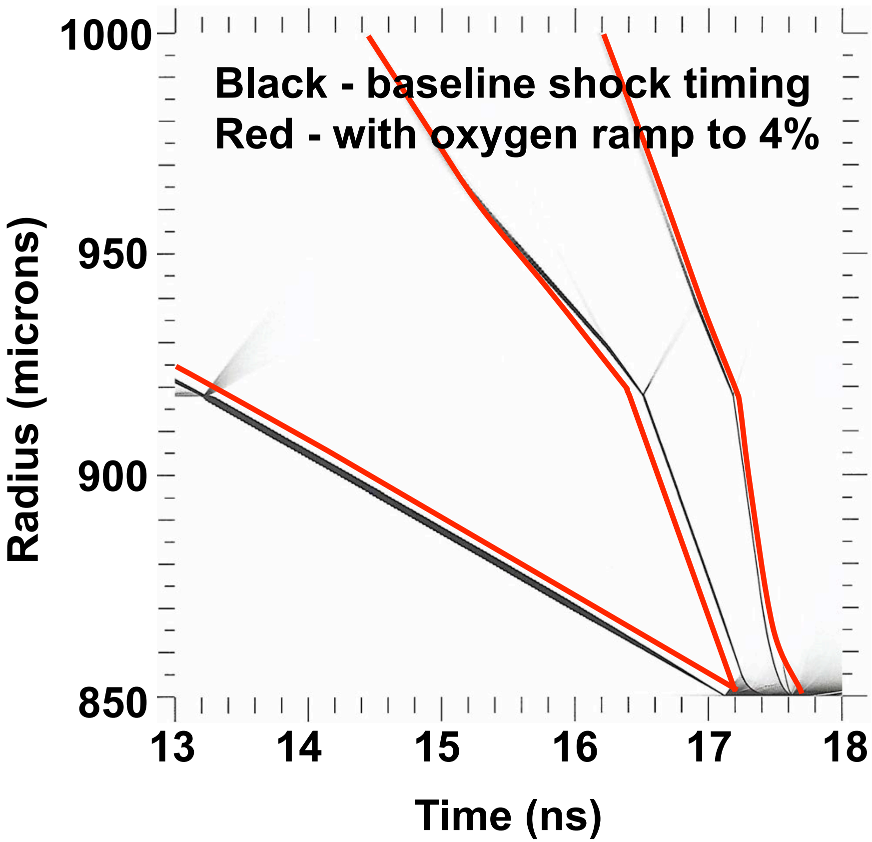




Requirement is "Average Oxygen < 1 at%"
Each 1 at% reduces velocity by 1.9%, we need implosion velocity within 3% of nominal for ignition

An oxygen ramp near the ablator surface changes the shock timing





- Oxygen profile ramping up to 4% over 50 microns changes shock timing by 50 ps, which is 1x spec for Keyhole shock timing
- Because it changes several shocks, changes adiabat from 1.44 to 1.472, loss of 8.5% in ITF
- If Keyholes set timing with this ramp, and this is reproducible for Keyholes and THD/DTs, it doesn't matter

We are requesting a bewildering array of capsules

Original campaign goal was "tune the laser pulse for the Rev5 point design" which allowed for focused target fabrication

Now we are optimizing the target design experimentally, which opens up a huge parameter space to try to explore

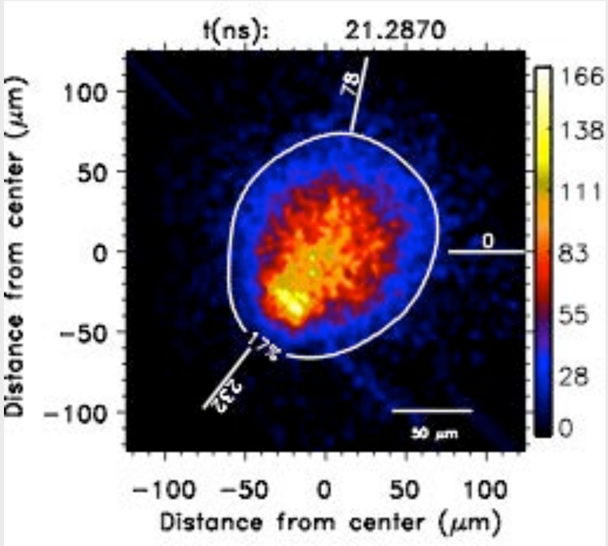
Target options now include:

1. **Two thicknesses, in addition to nominal (+20µm, +40µm)**
2. **Various dopant configurations (1.5x, 2x, sometimes 3x, uniform Si 1% or 2%, all with or without Ge)**
3. **Au and U hohlraums**

This is stressing to the target fab team and we are very grateful to you for your work to accommodate all the options!

We are working to implement a round of improvements in target features

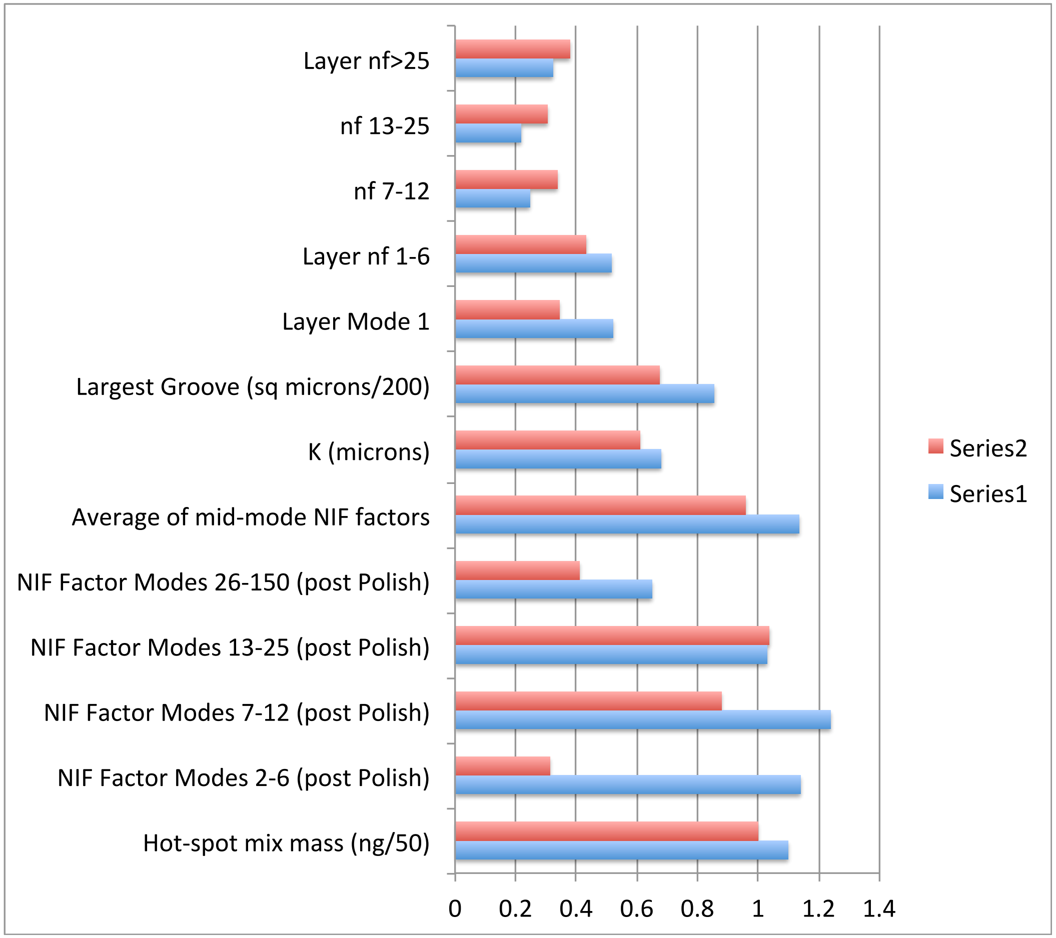
- Radiation loss through diagnostic hole at the waist is calculated to change the symmetry significantly, and we do suggestions of the asymmetry in implosions. Currently hole is plugged with HDC (to keep it open!). Fix by coating inside of HDC plug with Au
- Also cover starburst with thin Au film
- Fill tube often causes visible perturbation. Have developed 5μm tubes, will begin shooting next month
- Working to develop thinner tents
- Improved surface roughness (near term goal 20% better, long term 2x)
- Complete measurement of foreign surface material with “4pi”



Emitting core of symcap N110208 (with Ge) shows bright plume under fill tube

N120126 vs N120205 showed that incidental changes can change yield by 2x

- Two nominally identical shots. Second shot was intended to test effect of bad layer, but we got a good layer and shot it anyway
- Capsule and layer on second shot were very good. Yield was twice as good!



- Red N120205, better performer
- Everything on this bar chart is ideally small, so N120205 was better in every way except ice layer modes 12 and up
- It is tempting to ascribe better performance to major differences (CH modes 2-6) but maybe performance is very sensitive to something else (modes 7-12), or something else entirely (dust?)

Designs with Be and diamond ablators are on the planning horizon

- I don't have pie diagrams to show, since both designs are very much still in flux
- We have fabricated preliminary designs, and plan to test them this summer, but for both ablators the "real" design will be different from these preliminaries
- Preliminary tests *will* address the principal questions about the designs:
  1. Is the low velocity we see in GDP similarly low for Be and HDC?
  2. How are the laser-plasma instabilities for these ablators, with appropriate pulse-shapes
  3. Are the hydrodynamic instabilities (and capsule yield) qualitatively different?
  4. Maybe the experimental results will provide guidance on doping and drive
- Final designs are evolving because the preheat part of the x-ray drive spectrum (~2keV) is higher than we expected a couple years ago, and getting the correct dopant is a challenge. Very high Z (e.g. W) is a problem if it mixes into the igniting core; Si or Al, anything between Na and Ar in periodic table, up to 4-5 at%, would be wonderful

The National Ignition Campaign is well underway, with many successes in hand and some challenges ahead

- We have successfully fielded all of the experimental platforms planned for NIC, and used the results to adjust the target design and laser pulse
- Generally, the design and requirements remain essentially the same as before the campaign began
- There have been some minor adjustments:
  - Si dopant instead of Ge
  - New hohlraum dimensions
  - For the future, emphasis is on exploring wide range of targets including new ablators, various Si configurations, thicker shells

The target fabrication community deserves to be hugely congratulated for successfully fielding a wide variety of complex targets, meeting all requirements and a demanding schedule


NIC